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UNITED STATES PATENT APPLICATION

FOR

METHOD AND APPARATUS FOR CONVERTING FROM A SOURCE COLOR SPACE TO A TARGET COLOR SPACE

BY

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METHOD AND APPARATUS FOR CONVERTING FROM A SOURCE COLOR SPACE TO A TARGET COLOR SPACE

RELATED APPLICATIONS

[01] The present application is related to commonly owned (and filed on even date) United States Patent Applications: (1) United States Patent Application Serial No. ________________ entitled "HUE ANGLE CALCULATION SYSTEM AND METHODS"; (2) United States Patent Application Serial No. ________________ entitled "METHOD AND APPARATUS FOR CONVERTING FROM SOURCE COLOR SPACE TO RGBW TARGET CENTER SPACE"; (3) United States Patent Application Serial No. ________________ entitled "GAMUT CONVERSION SYSTEM AND METHODS", which are hereby incorporated herein by reference.

BACKGROUND

[02] In commonly owned United States Patent Applications: (1) United States Patent Application Serial No. 09/916,232 ("the '232 application"), entitled "ARRANGEMENT OF COLOR PIXELS FOR FULL COLOR IMAGING DEVICES WITH SIMPLIFIED ADDRESSING," filed July 25, 2001; (2) United States Patent Application Serial No. 10/278,353 ("the '353 application"), entitled "IMPROVEMENTS TO COLOR FLAT PANEL DISPLAY SUB-PIXEL ARRANGEMENTS AND LAYOUTS FOR SUB-PIXEL RENDERING WITH INCREASED MODULATION TRANSFER FUNCTION RESPONSE," filed October 22, 2002; (3) United States Patent Application Serial No. 10/278,352 ("the '352 application"), entitled "IMPROVEMENTS TO COLOR FLAT PANEL DISPLAY SUB-PIXEL ARRANGEMENTS AND LAYOUTS FOR SUB-PIXEL RENDERING WITH SPLIT BLUE SUB-PIXELS," filed October 22, 2002; (4) United States Patent Application Serial No. 10/243,094 ("the '094 application), entitled "IMPROVED FOUR COLOR ARRANGEMENTS AND EMITTERS FOR

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SUB-PIXEL RENDERING," filed September 13, 2002; (5) United States Patent Application Serial No. 10/278,328 ("the '328 application"), entitled "IMPROVEMENTS TO COLOR FLAT PANEL DISPLAY SUB-PIXEL ARRANGEMENTS AND LAYOUTS WITH REDUCED BLUE LUMINANCE WELL VISIBILITY," filed October 22, 2002; (6) United States Patent Application Serial No. 10/278,393 ("the '393 application"), entitled "COLOR DISPLAY HAVING HORIZONTAL SUB-PIXEL ARRANGEMENTS AND LAYOUTS," filed October 22, 2002; (7) United States Patent Application Serial No. 01/347,001 ("the '001 application") entitled "IMPROVED SUB-PIXEL ARRANGEMENTS FOR STRIPED DISPLAYS AND METHODS AND SYSTEMS FOR SUB-PIXEL RENDERING SAME," filed January 16, 2003, novel sub-pixel arrangements are therein disclosed for improving the cost/performance curves for image display devices and herein incorporated by reference.

[03] For certain subpixel repeating groups having an even number of subpixels in a horizontal direction, the following systems and techniques to affect proper dot inversion schemes are disclosed and are herein incorporated by reference: (1) United States Patent Application Serial Number 10/456,839 entitled "IMAGE DEGRADATION CORRECTION IN NOVEL LIQUID CRYSTAL DISPLAYS"; (2) United States Patent Application Serial No. 10/455,925 entitled "DISPLAY PANEL HAVING CROSSOVER CONNECTIONS EFFECTING DOT INVERSION"; (3) United States Patent Application Serial No. 10/455,931 entitled "SYSTEM AND METHOD OF PERFORMING DOT INVERSION WITH STANDARD DRIVERS AND BACKPLANE ON NOVEL DISPLAY PANEL LAYOUTS"; (4) United States Patent Application Serial No. 10/455,927 entitled "SYSTEM AND METHOD FOR COMPENSATING FOR VISUAL EFFECTS UPON PANELS HAVING FIXED PATTERN NOISE WITH

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REDUCED QUANTIZATION ERROR"; (5) United States Patent Application Serial No. 10/456,806 entitled "DOT INVERSION ON NOVEL DISPLAY PANEL LAYOUTS WITH EXTRA DRIVERS"; and (6) United States Patent Application Serial No. 10/456,838 entitled "LIQUID CRYSTAL DISPLAY BACKPLANE LAYOUTS AND ADDRESSING FOR NON-STANDARD SUBPIXEL ARRANGEMENTS".

[04] These improvements are particularly pronounced when coupled with sub-pixel rendering (SPR) systems and methods further disclosed in those applications and in commonly owned United States Patent Applications: (1) United States Patent Application Serial No. 10/051,612 ("the '612 application"), entitled "CONVERSION OF RGB PIXEL FORMAT DATA TO PENTILE MATRIX SUB-PIXEL DATA FORMAT," filed January 16, 2002; (2) United States Patent Application Serial No. 10/150,355 ("the '355 application"), entitled "METHODS AND SYSTEMS FOR SUB-PIXEL RENDERING WITH GAMMA ADJUSTMENT," filed May 17, 2002; (3) United States Patent Application Serial No. 10/215,843 ("the '843 application"), entitled "METHODS AND SYSTEMS FOR SUB-PIXEL RENDERING WITH ADAPTIVE FILTERING," filed August 8, 2002; (4) United States Patent Application Serial No. 10/379,767 entitled "SYSTEMS AND METHODS FOR TEMPORAL SUB-PIXEL RENDERING OF IMAGE DATA" filed March 4, 2003; (5) United States Patent Application Serial No. 10/379,765 entitled "SYSTEMS AND METHODS FOR MOTION ADAPTIVE FILTERING," filed March 4, 2003; (6) United States Patent Application Serial No. 10/379,766 entitled "SUB-PIXEL RENDERING SYSTEM AND METHOD FOR IMPROVED DISPLAY VIEWING ANGLES" filed March 4, 2003; (7) United States Patent Application

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Serial No. 10/409,413 entitled "IMAGE DATA SET WITH EMBEDDED PRE-SUBPIXEL RENDERED IMAGE" filed April 7, 2003, which are hereby incorporated herein by reference.

BRIEF DESCRIPTION OF THE DRAWINGS

[05] The accompanying drawings, which are incorporated in, and constitute a part of this specification illustrate exemplary implementations and embodiments of the invention and, together with the description, serve to explain principles of the invention.

[06] **FIG. 1** shows one embodiment of a general color conversion diagram.

[07] **FIG. 2** shows another embodiment of a general color conversion diagram.

[08] **FIG. 3** shows yet another embodiment of a general color conversion diagram.

[09] **FIG. 4** depicts one embodiment of a gamut pipeline as made in accordance with the principles of the present invention.

[010] **FIGS. 5** and **6** depict one embodiment of a hardware optimization for implementing an efficient 3xN multiply unit in a multi-primary conversion system.

[011] **FIGS. 7** and **8** show yet another embodiment of a hardware optimization for an efficient multiplier for a RGBW system.

[012] **FIG. 9** depicts one embodiment of a chromaticity diagram for an example multi-primary system with 4 primaries, RGB and C where C is cyan.

DETAILED DESCRIPTION

[013] Reference will now be made in detail to implementations and embodiments, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts.

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[014] Most monitors and TVs today were designed to display three-valued color data such as RGB and sRGB (sometimes called non-linear RGB or R'G'B') or three-valued chroma/luminance signals such as YIQ or YCbCr. To make brighter displays and displays with larger color gamuts, manufacturers are starting to consider multi-primary displays. These displays will have more than three primary colors. However, there are no convenient sources of multi-primary image data, and there are a large number of sources of three-valued color data that should be converted to the new multi-primary displays. A method and apparatus is provided to convert existing three valued color data into multi-primary data for this new class of displays. The present method and apparatus will work for multi-primary displays with any number of color primaries.

[015] One conventional color conversion system 100 is depicted in **FIG. 1**. This approach treats RGB image data conversion -- as a mapping from one color-space to another. This is commonly done between color output devices, for example converting RGB data intended for a monitor to a form that can be printed on a color printer. The traditional way to do this is to convert a source color image data 102 to CIE XYZ 106, then to convert that to the target color, for perhaps, another color device 110, as in **FIG. 1**. There are standard formulas, or conversion matrices (M1 104 and M2 108), to convert common color-spaces, such as RGB, into CIE XYZ and back again. For each output device, a different matrix can convert CIE XYZ for that particular device.

[016] One embodiment 200 of the present system, as shown in **FIG. 2**, calculates a conversion matrix 208 for mapping CIE XYZ data 206 into multi-primary data for rendering on a multi-primary display 210 (i.e. a display having any number of colored subpixels greater than

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three colors). **FIG. 3** depicts yet another embodiment 300. In this embodiment, the matrices for mapping RGB data 302 to CIE XYZ and then from CIE XYZ to multi-primary data for display 306 are combined into one matrix 304 that converts directly from RGB in one step.

[017] Although the conversion from three-value to multi-primary is depicted as one mathematical step in **FIG. 3**, there may be other desirable steps and/or subsystems in other embodiments. **FIG. 4** shows yet another embodiment of a "gamut pipeline" system 400. Thus, for example, in the conversion from three valued data (e.g. sRGB data, RGB, or the like at 402) to multi-primary, it may be desirable to perform one or more of the following steps and/or subsystems, such as an input gamma 404 and output gamma 414, a conversion from RGB to a color-space with separate chroma and luma 406, gamut conversion 408, hue angle converter 410, a multiprimary converter 412. In some embodiments, some of these steps may not be required or desired. For example, if the three-value color input is YCbCr instead of RGB, the conversion to separate chroma and luma is not desired. If the input data is sRGB, or RGB data with a nonlinear transform applied to it as in most images stored on computers, then the input gamma step is not desired. If the intermediate separate chroma/luma space used is CIE Lab, this space has an implied gamma and also includes the input gamma table. Thus, the general architecture of **FIG. 4** is variable to allow a pass-by mode for optional subsystems – depending upon the requirements of any complete system incorporating the present invention. Alternatively, these optional subsystems could be deleted altogether – resembling a much simplified system, as shown in **FIG. 3**.

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Chroma Luminance Converter

[018] Many conventional video devices convert back and forth between RGB and separate chroma/luma color systems. In fact, such a converter is an off-the-shelf item that is readily available for use in hardware implementations. For the purposes of the present invention, such a conventional chroma/luma converter would suffice in the present system. However, in some cases, it may be desirable to design the algorithms and hardware in such a manner as to reduce costs of the design. Also, it may be desirable to calculate the chroma information as part of an intermediate step to calculate a hue angle, as will be discussed in greater detail below. Thus, the information needed may differ or be more easily computed with the present methods and system described herein.

[019] In a first embodiment of a chroma/luma converter, Equation 1 shows a formula for a first conversion that has conversion constants which are all powers of two and thus easy to implement as shifts in hardware.

$$\begin{aligned} Y &= R/4 + G/2 + B/4 \\ By &= B\text{-}Y \qquad \text{Equation (1)} \\ Ry &= R\text{-}Y \end{aligned}$$

[020] In Equation 1, Y is the luminance component and By,Ry are the chrominance components. The formula for Y is similar to the standard conversion of RGB to luminance; except that red and blue colors are given equal luminance weight. For other applications, it may be possible in another embodiment to weight the chroma components differently. It may also be desirable to weight the chroma components in such a way as to simultaneously reduce the cost to

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implement the system. Equation 2 describes alternate weighted relationships that are also easy to implement in digital logic.

$$Y = (2*R + 4*G + G + B)/8$$

$$By = B-Y \qquad \text{Equation (2)}$$

$$Ry = R-Y$$

[021] In Equation 2, the green value is multiplied by 5/8ths by first multiplying by 4 then adding one more copy, then eventually divided by 8. If done in floating point, this formula would look like: Y=0.25*R+ 0.625*G + 0.125*B. This compares favorably to the REC 709 conversion formula for luminosity: Y=0.2127*R + 0.7152*G + 0.0722*B. Using Equation 2 to convert RGB to chroma/luma is reasonably close for intermediate calculations but can be easily implemented with shifts and adds in hardware. Equation 2 thus gives a transformation from RGB space to a new color-space -- YByRy.

Gamut Converter

[022] Multi-primary displays are considered to produce a display that can render more of the colors visible to the human eye than previous, conventional 3-color displays. However, most of the computer images and TV programming that currently exists was created with the assumption of the reduced gamut of TVs and computer monitors. One of the assumptions of a gamut converter is that TV cameras, digital cameras, and other input devices do not destroy the expanded gamut of the real world, but compress much of it into the limited gamut that they can represent. Thus, it may be desirable to reconstruct the full gamut in image sources by stretching the gamut back out again. This optional gamut conversion block 408 of **FIG. 4** is further

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disclosed in the copending application entitled "GAMUT CONVERSION SYSTEM AND METHODS" and incorporated herein by reference.

Multi-Primary Converter

[023] Now it will be described a system and a method for generating the matrix for converting from one space (for example, CIE XYZ) to another space for rendering on a multi-primary display. Once such a matrix or mapping (e.g. CIE XYZ to multi-primary) is constructed, it may be combined with other conversion matrices to create a single matrix (for example, via matrix multiplication), so that a separate conversion to an intermediate space (e.g. CIE XYZ) is actually never performed. In one embodiment, if, in an earlier optional step, the input data is converted to YCbCr, there exists a standard matrix for converting this to RGB. There also exists a standard matrix for converting RGB to XYZ. These two matrices can be combined (i.e. multiplied) with the CIE XYZ to multi-primary matrix to create a single matrix that performs a direct conversion from YCbCr to multi-primary.

[024] As is known, the CIE XYZ color space is versatile in that this color space can encode any color that is visible to a "standard observer" so it essentially encodes all the colors of human vision. Thus, if one has a way to convert any color on your input or output device into CIE XYZ and back, then you can convert to or from any other calibrated device. There are standard transformation matrices for converting from RGB to CIE XYZ and back again. These standard transformation matrices (also known as "recommendations" or "Rec") are based on the typical values of the primary colors and white point of a display device are often good enough for casual color conversions and calculations. Several of these standards are the "CIE Rec 601-1", "CIE Rec 709" or the "CIE XYZ itu". The white points for these recommendations have names

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like "D50" "D65" or "Illuminant E". Each recommendation has a slightly different chromaticity value for each of the red green and blue primary colors and a different white point value.

[025] These standard recommendations are approximations and it is considered more accurate to measure the chromaticity values of the primary colors of a specific display model and calculate a transformation matrix tailored for that model of display. To do this, e.g., the chromaticity of each primary color and the CIE XYZ tri-stimulus values of the white point is typically measured. Chromaticity values are pairs of "little x" and "little y" values -- x_r,y_r for the red primary, x_g,y_g for the green and x_b,y_b for the blue. There is a "little z" value as well, but this can be calculated from the x and y values with the formula z = 1-x-y. With just these four pieces of information (three primary chromaticity values and one XYZ white point), it is possible to calculate the transformation matrices as follows:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} x_r \cdot Cr & x_g \cdot Cg & x_b \cdot Cb \\ y_r \cdot Cr & y_g \cdot Cg & y_b \cdot Cb \\ z_r \cdot Cr & z_g \cdot Cg & z_b \cdot Cb \end{pmatrix} \cdot \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

Equation (3)

[026] Equation 3 shows the formula for converting from RGB values to XYZ. The Cr, Cg and Cb values are linear weighting values that must be calculated for a particular family of displays. Given the white point XYZ values, (Xw Yw Zw) and knowing that this translates into RGB values of (1 1 1), equation 3 can be re-written into the following form:

$$\begin{pmatrix} X_w \\ Y_w \\ Z_w \end{pmatrix} = \begin{pmatrix} x_r & x_g & x_b \\ y_r & y_g & y_b \\ z_r & z_g & z_b \end{pmatrix} \cdot \begin{pmatrix} Cr \\ Cg \\ Cb \end{pmatrix}$$

Equation (4)

[027] Equation 4 can be solved for (Cr Cg Cb) by inverting the matrix of chromaticity values and multiplying by the white point vector. The resulting Cr Cg and Cb values can then be

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substituted into Equation 3 creating a matrix that converts from RGB to XYZ. The inverse of that matrix can be used to convert from XYZ to RGB.

[028] Now, in order to convert into a color space with more than three coordinates (i.e. multi-primary space), then additional processing is required. This is primarily because of the fact that Equations 3 and 4 have square matrices that can be inverted to calculate intermediate values and to calculate reverse transformation matrices. However, when there are non-square matrices involved, inverse operations are problematic. For example, the following matrices are depicted transforming RGBC (where "C" is cyan; but any other color may suffice; or, alternatively, any four colors C1,C2, C3, and C4 would suffice) space into XYZ space:

$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} x_r \cdot Cr & x_g \cdot Cg & x_b \cdot Cb & x_c \cdot Cc \\ y_r \cdot Cr & y_g \cdot Cg & y_b \cdot Cb & y_c \cdot Cc \\ z_r \cdot Cr & z_g \cdot Cg & z_b \cdot Cb & z_c \cdot Cc \end{pmatrix} \cdot \begin{pmatrix} R \\ G \\ B \\ C \end{pmatrix}$ Equation (5)	$\begin{pmatrix} X_w \\ Y_w \\ Z_w \end{pmatrix} = \begin{pmatrix} x_r & x_g & x_b & x_c \\ y_r & y_g & y_b & y_c \\ z_r & z_g & z_b & z_c \end{pmatrix} \cdot \begin{pmatrix} Cr \\ Cg \\ Cb \\ Cc \end{pmatrix}$ Equation (6)

[029] If we knew the values of (Cr Cg Cb Cc) we would be able to convert from (R G B C) to XYZ. However, in Equation 6, the matrix is no longer square and cannot be inverted. There are four unknowns and only three equations, not enough information to find a unique solution. In actual fact, there are many solutions and one such solution might suffice if found. There are many different numerical techniques in the literature for finding solutions like this. Just as an example, MathCad uses several of these techniques (linear, conjugate gradient, Levenberg-Marquardt or quasi-Newton) to find numerical solutions. Starting from an initial

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guess for the unknown values – for one example set Cr, Cg, Cb and Cc all equal to 1 (of course other initial values are sufficient) -- these techniques search for better values until some condition is met. Equation 6 is a condition that could be used to do this search.

[030] However, when Equation 6 is used as the search condition, the solutions most often found are ones that result in one of the Cr, Cg, Cb or Cc values going to zero. So, it is desirable to find conditions on the equations that would result in solutions other than trivial ones. One embodiment of such a transformation matrix that may avoid this problem is given below:

$$\begin{bmatrix} (X_w)^2 \\ (Y_w)^2 \\ (Z_w)^2 \end{bmatrix} = \begin{bmatrix} (x_r \cdot Cr + x_g \cdot Cg + x_b \cdot Cb + x_c \cdot Cc)^2 \\ (y_r \cdot Cr + y_g \cdot Cg + y_b \cdot Cb + y_c \cdot Cc)^2 \\ (z_r \cdot Cr + z_g \cdot Cg + z_b \cdot Cb + z_c \cdot Cc)^2 \end{bmatrix} \qquad \text{Equation (7)}$$

[031] Equation 7 results from taking Equation 6 and symbolically expanding the right side of the equation and squaring the components of both sides. With Equation 7, it should be possible to find results that do not involve one of the primaries going to zero. With Equations 7 and 6 together as conditions for the solution, it is possible to find yet another non-zero solution. There are possibly many (and perhaps an infinite number of) solutions but it suffices to find one of them for the purposes of the present invention. Of course, the present invention encompasses other conditions to find a non-trivial solution and the present invention should not be limited to the recitation of any one or few numbers of such conditions.

[032] When we have actual displays -- displays with different primaries or displays with more than four primaries -- then either Equation 4 or 5 may fail to find a solution in some of these situations. In that case, it may be desirable to find another condition equation that allows the numerical search algorithm to find a useful solution.

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[033] The solution to equation 5 is a set of Cr, Cg, Cb and Cc values that can be substituted into Equation 3, which can now convert any 4-primary (R G B C in this case) value into CIE XYZ. The above procedure was demonstrated with a 4-primary system, but this procedure works just as well with any number of primaries. Converting from multi-primary to CIE XYZ is a useful task but what is more useful would be to convert CIE XYZ value into (R G B C) or some other multi-primary system.

Converting CIE XYZ to multi-primary

[034] The matrix in Equation 5 is not square so it cannot be inverted and the equation cannot be simply solved to convert from CIE XYZ. Of course, if the matrix could be inverted, the result would look similar to this:

$$\begin{pmatrix} R \\ G \\ B \\ C \end{pmatrix} = \begin{pmatrix} R1 & R2 & R3 \\ G1 & G2 & G3 \\ B1 & B2 & B3 \\ C1 & C2 & C3 \end{pmatrix} \cdot \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

Equation (8)

[035] Although the solution cannot be solved for by inverting a matrix, it is possible to glean an inverse equation and it should be able to test to see if the transformation matrix is a correct one. One embodiment might be to convert all the primary colors to CIE XYZ using equation 5. In the case of a 4-primary system, we would then have five known input and output values (4 primaries plus the white point) and could use them as condition equations. However, this may be difficult because there may be too many restrictions on the system to find a linear solution. The analogous situation might be to find a single straight line through a collection of points. In the case of solving Equation 8, we are trying to find a linear equation, a plane that

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passes through all of our primary points and the white point in a 4 dimensional space. There will always be a plane that passed through three of these points, but if trying to find one through all the points may be difficult.

[036] However, given that there is always a solution to the case with three points, it is possible to formulate a general way to convert from CIE XYZ to any multi-primary system. It is possible to find a matrix for Equation 8 that works if the image data point is inside a chromaticity triangle – for example, between the red, green and white point. Likewise, a matrix for Equation 8 may be found that works for a point is inside the chromaticity triangle between the green, cyan, and white point, etc., e.g., as shown in **FIG. 9**. In general, no matter how many primaries a system has, it should be possible to break the color space down into regions (for example, triangles or some other shapes) that are bounded by the white point and two primaries. Additionally, it may not be required that the regions are disjoint – i.e. it may be possible to define solution matrices for regions that have overlapping color points. For each triangle or region, a matrix for Equation 8 should always be found that converts CIE XYZ to multi-primary inside that triangle or region.

[037] In addition to the fact that the regions may be other than triangles for the purpose of the present invention, it is also possible to define another point – i.e. other than the white point – in which to calculate solution matrices. In fact, it may be desirable to choose other points that are off-white to in which to calculate solutions – possibly in regards to backlighting conditions. Of course, for purposes of the present invention, any other point in the interior of the target color space might suffice for suitable solutions matrices for converting to a multi-primary color space.

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[038] For yet another embodiment, it is possible that the source color space has N primaries and the target color space has N+1 or more primaries – such that there is less than N primaries in common between the source and the target color spaces (with the extreme case being that there are no primaries in common between the source and the target color spaces). Having primaries in common is not a requirement of this invention, since the intermediate colorspace of CIE XYZ is used. For example, monitors are typically RGB while printers are typically CMY and yet conversions between the two are routinely done. In the case of N source primaries and N+1 or more target primaries, the method for generating conversion equations proceeds as described above. Because there may not be standard recommended conversion equations for the source color space, the procedure may have to be done twice, once to generate conversion equations to convert the source space to CIE XYZ and a second time to generate conversion equations to convert CIE XYZ to the target color space. Then the resulting matrices can be combined together to do the conversion directly without going through the intermediate CIE space.

[039] For each triangle, the CIE XYZ tristimulus values of each corner can be calculated using equation 5 above. These three known points can then be used as test conditions in a numerical solver for finding a matrix for Equation 8. On the lines between the triangles, the matrix for the triangle on either side can be used since this line segment is a locus where both transformations are restricted to produce the same results. Each of these matrices will have rows that are unique and rows that repeat (where repeating rows may appear anywhere). Table 1 shows the exemplary matrix for the red-green-white triangle in RGBC color space.

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2.166792	-0.850238	-0.192135
-1.778663	3.483939	-0.728554
0.024661	-0.175291	1.057744
0.024661	-0.175291	1.057744

Table 1

4.962725	-4.231465	0.47251
-4.849038	9.749895	-3.802703
-0.04661	0.003508	0.955759
-0.04661	0.003508	0.955759
-0.04661	0.003508	0.955759
-0.04661	0.003508	0.955759
-0.04661	0.003508	0.955759

Table 2

[040] In this Table 1, it should be noted that the rows that are not related to the primary corners of the associated triangle are identical. This will generally be true of any matrix generated this way for any primary system. Table 2 shows this in an extreme case (e.g. RYW triangle in R,Y,G,T,C,B,M –where T is turquoise and M is magenta) that has 7 primaries. The identical rows in Table 3 refer to "outside of the triangle" primaries (i.e. not R and not Y) that are restricted to linearly change from 0 to 1 from the outside edge to the white point. Knowing that many of the values in these matrices will be identical can lead to optimizations in the hardware implementation. The storage for the matrix in Table 2 could be reduced, for example. Also the calculation of the multi-primary values could be simplified by knowing that many of the multiplications are done with the same constant values. This will be discussed below as 3xN multiplier hardware optimization.

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[041] To convert a CIE XYZ value to multi-primary, it is desirable to determine which chromaticity triangle the color is in and use the corresponding matrix to do the conversion in Equation 8. The XYZ values can be converted to xyY chromaticity and then tested against the original chromaticity co-ordinates. Although this works well, it could be computationally very expensive to do at full speed in a monitor. In another embodiment, there is a single 3x3 matrix multiply that could determine if a point is in a triangle. This is also computationally intensive, but may be reasonable in some architectures where this is a common operation. Graphics adapter cards for PC computers often have this capability as part of their texture mapping capability. The input color values can be converted to some hue based color co-ordinate system and then the hue angle could be used to determine which triangle the color is in. The hue angle is something that may be calculated for other reasons, for example it is important to many gamut expansion algorithms. So this information may already be available and could be used to choose the transformation matrix with little or no increase in computational complexity.

Hue Angle Calculator

[042] When doing multi-primary conversion as described above, it was desirable to calculate the hue angle and use it as an index to select a conversion matrix. One improved embodiment of a hue angle calculator comes from changing the number of degrees around a circle from 360 to a power of 2 – e.g. 256. Units of angle having only 256 "degrees" around a circle is easier to implement in hardware. This and other embodiments are disclosed in one of the co-pending, related applications mentioned above.

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RGBW special case

[043] RGBW is a display with 4 primaries where three of them are the usual red, green and blue but the fourth primary is pure white. This type of display is of interest because the addition of white can increase the brightness. One of the "primaries" is white and lies underneath the white-point. Despite this situation, it is still possible to build a set of multi-primary matrices to convert CIE XYX to RGBW. This is disclosed in yet another co-pending, related application mentioned above.

3xN multiplier hardware optimization

[044] As mentioned in connection with Tables 1 and 2 above, **FIG. 5** shows one way of reducing the memory required to store the 3xN matrices – in this case, a six primary system. It was also mentioned above that there would be a way to take advantage of the identical rows in the hardware. **FIG. 6** shows how this can be done with a 3x3 multiplier and 6 multiplexors for the same 6-primary system. This is just one example, the same savings can be done with any number of primaries. As the number of primaries increases, the number of inexpensive multiplexors increases, but the number of expensive multipliers remains constant at 3x3.

[045] **FIG. 5** is a diagram showing one way to resize a list of 3x6 matrices for converting 3-valued colors for a 6-primary display. The top matrix is the one calculated for converting colors that lie inside the RYW triangle (where W is the center white-point). The rows for R and Y will have unique rows; while the rest of the rows will be identical. These identical rows are shaded gray to indicate that they are identical. The rest of the 3x6 matrix diagrams are for the other five chromaticity triangles and have the rows for the base colors shaded white while the identical rows are shaded gray. Any system can be used to compress these matrices into 3x3

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matrices, as long as both of the unique rows are copied along with one of the identical rows. In **FIG. 5**, several other rules are used, but these are arbitrary as long as the connections to the multiplexors in **FIG. 6**, as described below, are changed to match. The arbitrary rules used in **FIG. 5** are that the red row is always copied to the top of the 3x3 matrix, and the rows copied are kept in their original order.

[046] **FIG. 6** shows how to use the 3x3 matrices from **FIG. 5** to perform multi-primary conversions. Three valued colors are presented to the 3x3 matrix multiplier and one of the 6 matrices is chosen based on the triangle number of the input color, calculated as described in a related application regarding hue angle calculations. The 3x3 matrix multiplier performs the 9 multiplies (and several additions to complete a matrix multiply) and outputs 3 values. These three values are distributed as the 6 output signals by 6 multiplexors. The multiplexors also use the chromaticity triangle number as their input to select different values. The three multiply results are wired to the 6 multiplexors depending upon the rules used to compact the original multi-primary matrices into 3x3 matrices. For example, the rule that the red row is always put in the top row of the 3x3 matrices means that the red multiplexor always selects the first matrix multiplier result. Thus, the red multiplexor is somewhat unnecessary, but it is left in as an example. It should be appreciated that the same hardware optimization can be applied to an N primary system where N is typical greater than 3.

[047] **FIG. 7** shows the special case for RGBW when W (white) is one of the primaries. Because W is typically contains a row identical to one of the others, it can be removed from the 3x3 matrices. Also in the case of RGBW, only 3 rows remain after removing W and these can be kept in their original order. Because of this, the multiplexors for R G and B are can be removed,

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as shown in **FIG. 8**. Only one multiplexor for W may be desirable to choose the correct value from the other primaries.

[048] In the above embodiments, reference to functional blocks can be implemented using any combination of hardware and/or software, including components or modules such as one or more memory devices or circuitry. For example, a programmable gate array or like circuitry can be configured to implement such functional blocks. In other examples, a microprocessor operating a program in memory can also implement such functional blocks.

[049] While the invention has been described with reference to an exemplary embodiment, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.

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